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LATE STAGES IN THE EVOLUTION OF GALACTIC NOVAE IN OUTBURST

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FINAL REPORT

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We made significant progress in our understanding of the final stages of evolution of novae in outburst. In this final report, which is accompanied by a brief resume, I will concentrate on only 3 outbursts: Nova V1974 Cyg 1992, Nova GQ Mus 1983, and Nova RS Oph 1985. Each of these novae was very different from the other two and IUE provided useful and unique data on a particular outburst.

I first discuss the IUE observations of the combined X-ray and UV turnoff of GQ Mus. Both GQ Mus and V1974 Cyg were observed to turnoff in X-rays by ROSAT. The turnoff of V1974 Cyg was also observed with EUVE. GQ Mus was observed near the beginning of its outburst with EXOSAT and then 7 years later by ROSAT in the All Sky Survey. Later ROSAT PSPC observations showed that its X-ray intensity was slowly declining with time and it was not detected in the last pointing that occurred in August 1993. We observed GQ Mus with IUE over the entire active phase of its outburst and found a change in the slope of the UV continuum around the time that the X-rays turned off. V1974 Cyg was observed by ROSAT throughout its entire active phase in X-rays which lasted about 18 months. V1974 Cyg was detected in the EUVE All Sky Survey, but not in pointed observations that occurred in August 1993 (and June and November 1994). We use the measured times of the active phases to determine important properties of these two novae. For example, for V1974 Cyg we predict that more than $10^{-5}M_{\odot}$ of helium rich material was left on the white dwarf when it returned to quiescence. For GQ Mus, about $10^{-4}M_{\odot}$ was left on the white dwarf. These results imply that a significant amount of the helium seen in nova ejecta was produced in outbursts prior to the one that was just observed. They also imply that the mechanism which mixes core material into the ejecta must be efficient.

We were also able to combine our IUE observations with X-ray observations of V1974 Cyg. In a recent paper, we presented new data on the variations of the ultraviolet nitrogen lines during the late, optically thin stages, of the outburst of V1974 Cygni. These show that after roughly JD 2449200 (1993 July), about 500 days after discovery, the ejecta reached maximum ionization and then started to recombine. The decline in ionization coincided with the X-ray turnoff observed with ROSAT. We derived densities for the ejecta at this stage, and used these to discuss the development of the ejecta. The decline with time of the UV emission lines, especially He II 1640Å, shows that the ejecta must have a linear velocity structure. This agrees with models for the ejection by an explosion and models that we have previously published for

the line profiles. We then model the variations of the X-rays from this nova. We show that the ROSAT rise can be modeled assuming a constant luminosity central source, at approximately the Eddington limit for a massive white dwarf and an effective temperature of about 4 x 10^5K, using only a decreasing X-ray optical depth within the ejecta, as previously noted by Krautter et al. (1996). This model can be generalized to explain the absence of X-ray emission during the early outburst stages of any nova. Lastly, we show that the final decline in the X-rays requires a substantial decrease in both the luminosity and temperature of the central star, in agreement with expectations for thermonuclear burnout on the surface of the white dwarf.

We also studied the 1985 outburst of RS Oph using spectra obtained with IUE and contemporaneous groundbased optical spectra. The low resolution integrated fluxes show that a short-lived constant bolometric luminosity phase existed in the early outburst. If this reached the Eddington luminosity, it implies a minimum mass for the white dwarf of $1.2M_\odot$. This and the lack of evidence for eclipses in ultraviolet low resolution spectra obtained in quiescence support the orbital solution of Dobrzycka and Kenyon (1994), in particular the low inclination of the system and the low mass, $0.5M_\odot$, of the red giant. The high resolution optical and ultraviolet line profiles showed the development of two separate contributors. One was a broad line component produced by emission from the high velocity ejecta. The other was a narrow line component produced in the portion of the red giant wind that was ionized by the UV pulse from the explosion and by radiation from the shock produced by the passage of the ejecta through the wind. The expanding Stroemgren sphere had two effects. Absorption from the overlying wind decreased against the ejecta and the ionized emitting gas, and the emission measure increased within the expanding H II region. We model these effects to show how the column density of the cool material decreased with time using the techniques developed in Shore and Aufdenberg (1993). We show that the increased ionization of the wind account for changes in the absorption line components in the ultraviolet and use this decrease and the narrow emission line ratios to determine the physical parameters for the line forming region in the wind. From this, we derive the mass loss rate for the red giant. In addition, we find evidence for a nitrogen overabundance in the wind from the time development of the N V 1240Å doublet. The primary source for ionizing the red giant wind was radiation produced by the shocked ejecta as they traversed the stellar wind. The shock-generated emission also powered the coronal species until about 100 days after outburst at which time shock breakout occurred. The ionized wind subsequently

recombined, although a hot source was still present on the white dwarf on the basis of continued visibility of the ultraviolet O III fluorescence lines and the IR He I 1.08μm line. Finally, we discuss how many of the techniques developed in this study of a photoionizing pulse propagating into a dense environment can be applied to the analysis of active galactic nuclei.

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